Original Communication

# Evaluation of meteorological factors on sudden cardiovascular death

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## ARTICLE INFO

## ABSTRACT

Climatic and seasonal triggering factors have received an increasing attention among risk factors of sudden cardiac death. The relationship between cold weather conditions and ischemic heart disease death is well established. In this study, there were 7450 (4967 males, 2483 females) cardiovascular death cases medico-legally autopsied between 1995 and 2004. In most of the cases (76%) cardiac death occurred at the scene, and 17% had acute ischemic heart disease. In order to examine the relationship between daily maximum, minimum and mean temperature, air humidity, air pressure, wind speed, global radiation and the daily numbers of death cases, statistical analysis were accomplished using correlation coefficients, and Box–Whisker-plot diagrams. A significant negative correlation was detected between daily mean temperature and cardiovascular mortality. A remarkable seasonal variation was found. Cold and dry weather may be an important risk factor in bringing on the onset of sudden cardiac death.

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## 1. Introduction

Climatic and seasonal triggering factors on human life have received an increasing public and social interest for centuries. In last years physicians and meteorologists pay attention on the relationship between meteorological events and their effects on human health.[1,2] Climatic research over the past two decades makes clear that Earth's climate will change in response to the atmospheric greenhouse gas accumulation. Meteorological factors have well-known effects on human health status and mortality. Detection and attribution of health effects to climate changes have become a key research challenge.[3] Climatic and seasonal triggering factors have received an increasing attention among risk factors of sudden death.[4]

Several studies have demonstrated that cardiovascular mortality has a seasonal distribution.[5–8] The relationship between cold weather and ischemic heart disease mortality is well established.[9–11] The cold temperature may be an important factor in bringing on the onset of life-threatening cardiac events, even in regions with relatively mild winters.[4] The relationship between increasing temperature and mortality has been reported since the early 20th century.[2,12–15]

Capital Budapest (with two millions of inhabitants) is located in Hungary, on the border of three different climate regions in Europe: (1) wet oceanic, (2) dry continental and (3) Mediterranean which means wet and dry conditions in winter and in summer, respectively. In this sensitive region, a relatively small displacement of climatic zones results in strengthening of one of the three main climatic influences.[16] However, most of the forecasts of increasing mortality are based on steady-state weather–mortality models implicitly assuming that weather–mortality relationships have not varied significantly over time.[2] Besides the global climate models, there is an increasing demand on fine-scale local analysis of climate effects.

The main purpose of this study was to determine whether or not the rate of fatal acute or chronic cardiovascular diseases detected during medico-legal autopsies has been affected by the different meteorological factors. In this study, we examined the cardiovascular sudden death cases with special regards to the gender, age, scene investigation, well-defined cause of death and post-mortem detected pathomorphological changes.

## 2. Material and methods

### 2.1. Mortality data

The survey target groups included cases of sudden cardiovascular deaths in capital Budapest. Information was collected from forensic autopsy records of the Department of Forensic

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Medicine, Semmelweis University. We extracted daily numbers of death victims who died at the scene or in the ambulance, without hospital treatment. There were 7450 (4967 males, 2483 females) such cases autopsied between 1 January 1995 and 31 December 2004. Data were analyzed according to the cause of death, age, gender, and scene of death. The average age of all persons was 49 years.

All the macroscopic post-mortem investigation was followed by a detailed histological examination. Sudden death cases were examined by forensic pathologists. The 10th revision of the International Classification of Diseases (ICD) was used for the determination of cause of death. This 10th revision of ICD with detailed codes was introduced in 1995 in Hungary.

We analyzed the levels of blood alcohol concentration (BAC) in 10.5% of all the cardiovascular death cases. Influence of alcohol was categorized as slight (BAC: 51–80 mg/100 ml), mild (BAC: 81–150 mg/100 ml), moderate (BAC: 151–250 mg/100 ml), severe (BAC: 251–350 mg/100 ml), and very severe (BAC: above 351 mg/100 ml). Alcohol-involved deaths were defined as those with detectable BAC of more than 50 mg/100 ml.

### 2.2. Meteorological parameters

For the evaluation of meteorological factors two meteorological databases were used:

(a) Meteorological data were obtained from the European Centre for Medium-Range Weather Forecast (ECMWF) ERA-40 database. We analyzed the meteorological data for every 6 h. The following variables were used: daily maximum temperature, daily minimum temperature, daily maximum temperature change (during 6 h), daily maximum and minimum air pressure, daily air pressure change (during 6 h), daily minimum difference between air temperature and dew point temperature, daily maximum wind speed, and the temperature of AT-850 hPa geopotential level.
(b) The urban climatic station (operated by Department of Meteorology Eötvös Loránd University and the Hungarian

Meteorological Service) was used. We calculated the daily maximum temperature, daily maximum temperature change (during 1 h), daily maximum relative humidity, and the daily maximum global radiation from the data detected by the urban climate station for every 10 min.

### 2.3. Statistical methods

First, we accomplished univariate analyses of the relationship between death cases and meteorological factors. We used Box–Whisker plot diagrams as a graphical tool for displaying our results. On these plots, we present five quartiles: the minimum, the lower quartile ($q_{0.25}$), the median ($q_{0.5}$), the upper quartile ($q_{0.75}$), and the maximum of the ranked sample (where $q_p$ means data value exceeding $p$ proportion of the data). These characteristic values are capable to display a sketch on the distribution of the dataset. Histograms of the relative frequency of different meteorological parameters were compared.

In order to examine the bivariate structure of the meteorological effects, we used scatter-plot diagrams and bubble diagrams to display two different meteorological parameters at the same time. Lower and upper terciles ($q_{0.33}$ and $q_{0.67}$, respectively) are used to separate the low, the average, and the high values of the meteorological parameters.

## 3. Results

### 3.1. Cardiovascular death cases

Cardiovascular death during the study period 1995–2004 were autopsied at the Department of Forensic Medicine, however, we included only 7450 deaths (75.8% of all the cardiovascular death) among persons died at the scene (home, street, public place) without hospital treatment. Table 1 shows the distribution of cause of death defined and coded according to the 10th revision of the ICD. The pathomorphological changes of different acute (acute myocardial infarction, pulmonary emboli, myocarditis, acute

**Table 1**
Distribution of the pathomorphological changes of acute and chronic diseases detected during the post-mortem investigation and coded according to ICD.

| Cause of death | ICD | Acute cardiac diseases, no (%) | Chronic cardiac diseases, no (%) | Acute vascular diseases, no (%) | Chronic vascular diseases, no (%) |
|---|---|---|---|---|---|
| Acute rheumatic fever | I01–I02 | 3 (0.2) | | | |
| Chronic rheumatic heart disease | I05–I09 | | 63 (1.6) | | |
| Hypertensive heart disease | I10–I15 | | | | 86 (4.1) |
| Acute ischemic heart disease | I20–I24 | 914 (67.7) | | | |
| Chronic ischemic heart disease | I25 | | 2707 (72.9) | | |
| Pulmonary embolism | I26–I28 | | | | 38 (1.8) |
| Pericarditis | I31–I32 | | | | 6 (0.2) |
| Endocarditis | I38–I39 | | 12 (0.3) | | |
| Non-rheumatic valve disorders | I34–I37 | | 48 (1.2) | | |
| Myocarditis | I41 | | 16 (0.4) | | |
| Cardiomyopathy | I42–I43 | | 77 (2) | | |
| Conduction disorders, cardiac arrhytmias | I44–I49 | 318 (23.5) | | | |
| Acute heart failure | I50 | 114 (8.4) | | | |
| Complications of heart diseases | I51–I55 | | 750 (20.2) | | |
| Cardiomegaly | I51.7 | | 39 (1) | | |
| Non-traumatic intracranial haemorrhage | I60–I69 | | | 158 (49.6) | |
| Atheroscelosis | I70 | | | | 1857 (89.6) |
| Aortic and other aneurysm | I71–I72 | | | 60 (18.8) | |
| Other peripheral vascular disease | I73 | | | | 17 (0.8) |
| Thrombophlebitis and venous embolism | I80–I82 | | | 98 (30.8) | |
| Varicose veins of lower extremities | I83–I84 | | | | 66 (3.1) |
| Oesophageal varices | I85 | | | 2 (0.6) | |
| Disorders of the circulatory system | I95–I96 | | | | 1 (0.04) |
| All: 7450 | | 1349 | 3712 | 318 | 2071 |
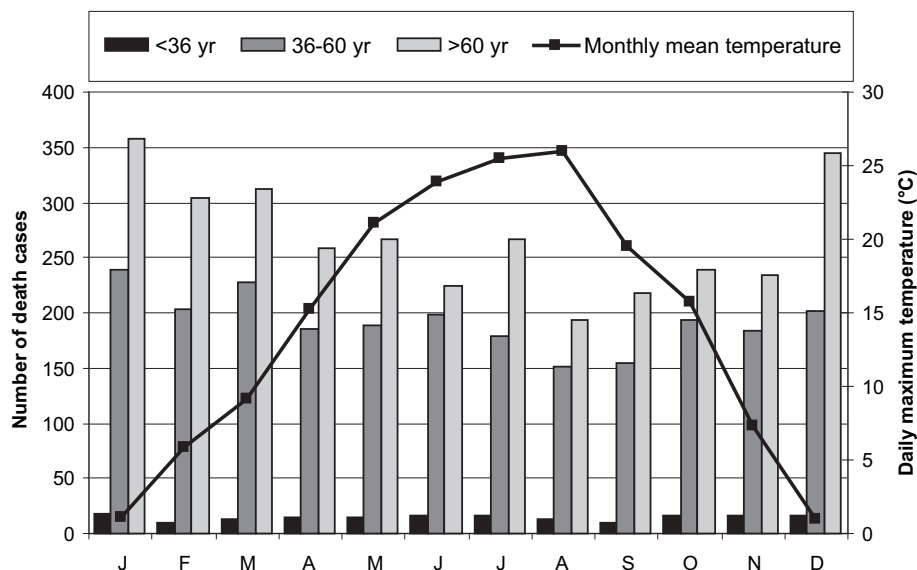
**Fig. 1.** Seasonal distribution of cardiovascular deaths cases in different age groups and the average daily maximum temperature.

endocarditis) and chronic (cardiomyopathy, coronary sclerosis, chronic heart failure) cardiovascular diseases were detected during the post-mortem medico-legal investigation. Fig. 1 demonstrates that number of cardiovascular death victims at older ages follows a definite seasonal distribution. The minimum of the death cases occurred in late summer, while the maximum in winter (December and January), which is negatively correlated with the seasonal distribution of temperature. We investigated the death cases according to the cause of death (acute cardiac, chronic cardiac, acute vascular, chronic vascular) and age groups. (Table 2).

Post-mortem blood alcohol tests were available in 10.5% (781/7450) of cases, with negative results in 220 (28.1%). BACs were evaluated and was slight degree in 292 (37.3%), mild degree in 65 (8.3%), moderate degree in 96 (12.3%), severe degree in 61 (7.8%), and very severe degree in 47 (6%) cases.

### 3.2. Relationship between mortality and meteorological parameters

Linear relationship between meteorological factors and daily number of sudden death cases was analyzed. The intensity of relationship was characterized by the correlation coefficients between the number of cardiovascular death cases and different meteorological factors.

### 3.3. Relationship between mortality and temperature

Box−Whisker plot diagrams of Fig. 2 demonstrate the distribution of the daily maximum and the AT-850 hPa temperature values in case of different numbers of daily cardiovascular deaths.

Both the median value and the quartiles tend to decrease as the daily number of death cases increases. Since the analysis of daily minimum temperature presents similar results, this highlights the negative relationship between temperature and death events.

Relative frequency distribution of daily minimum and maximum temperature is presented in Fig. 3 in case of 0, 1, 2 or 3, and more than or equal to 4 daily acute and chronic cardiovascular deaths. The histograms demonstrate that both the maximum and the minimum daily temperatures tend to be lower when more death cases occur in a day. For instance, daily maximum temperature is between 20 °C and 30 °C the most frequently (45% of all the temperature data) when no death case occurred, while it is between 0 °C and 10 °C with 40% relative frequency when at least four death cases occurred.

Scatter-plot analysis (Fig. 4) shows bivariate effect of daily maximum and minimum temperatures. On the days with four or more death cases, the daily maximum and minimum temperatures tend to be lower than on days without any cardiovascular death events.

Fig. 5 presents the bivariate distribution of the daily maximum temperature and the 6-h temperature change in case of the total cardiovascular and the acute cardiac deaths (0 death case is demonstrated in the upper panel, while more death cases are demonstrated in the lower panel). The largest frequency of cardiovascular death cases was detected in cold and cooling weather conditions.

As a summary of the above results, we found a significant negative relationship ($r = -0.093$/males, $r = -0.072$/females) between temperature and cardiovascular mortality. Table 3 demonstrates the estimated values of multiple discriminative analysis.

**Table 2**
Age distribution among acut and chronic cardiovascular death cases.

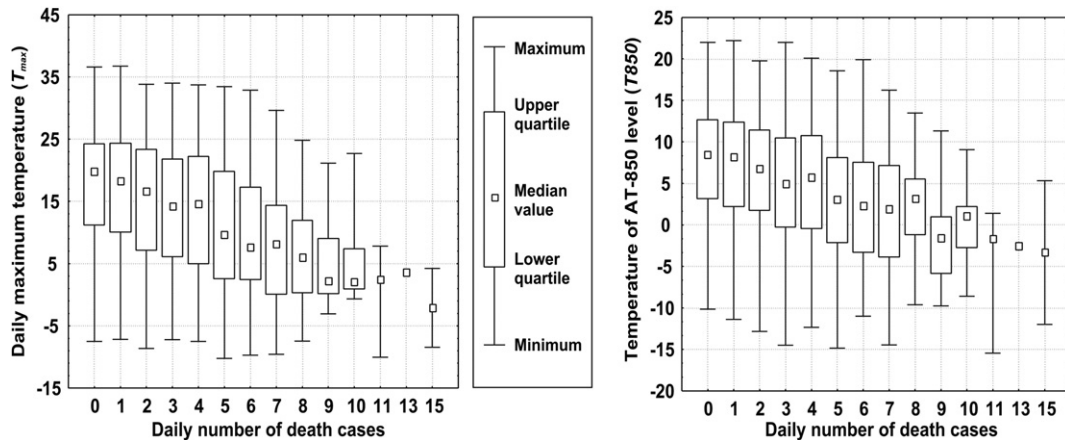| Age group (years) | Acute cardiac disease, no (%) | Chronic cardiac disease, no (%) | Acute vascular disease, no (%) | Chronic vascular disease, no (%) | All, no |
|---|---|---|---|---|---|
| 0−35 | 85 (33.8) | 125 (49.8) | 13 (5.1) | 28 (11.1) | 251 |
| 36−60 | 527 (17.9) | 1523 (51.9) | 114 (3.9) | 767 (26.1) | 2931 |
| >61 | 715 (17.1) | 2020 (48.3) | 189 (4.5) | 1254 (30) | 4178 |
| Unknown age | 22 (24.4) | 44 (48.8) | 2 (2.2) | 22 (24.4) | 90 |
| All | 1349 | 3712 | 318 | 2071 | 7450 |

**Fig. 2.** Results of Box–Whisker plot analysis – distribution of daily maximum and AT-850 hPa temperature values in case of the different daily numbers of cardiovascular death cases.

### 3.4. Relationship between mortality and air pressure, global radiation, relative humidity, wind

We analyzed the daily maximum and minimum air pressure and the daily 6-h air pressure change. Box–Whisker diagrams in Fig. 6 show that the median and the quartiles tend to increase with more daily cardiovascular deaths. The analysis of 6-h change of air pressure suggests that more acute or chronic vascular death cases occur during increasing air pressure conditions (implying cold weather fronts).

For the evaluation of daily global radiation, we used the data measured at the urban climatic station between 2000 and 2004.

Higher rate of acute cardiac and acute vascular mortality was detected when the daily global radiation was larger. Chronic cardiovascular death cases did not show similar results. Values of relative humidity and wind did not influence significantly the rate of sudden death.

### 4. Discussion

In our study univariate and bivariate statistical analyses were used to examine the entire database based on the number of daily death cases. We found a high frequency of cardiovascular death in cold weather and in less variable meteorological conditions. There
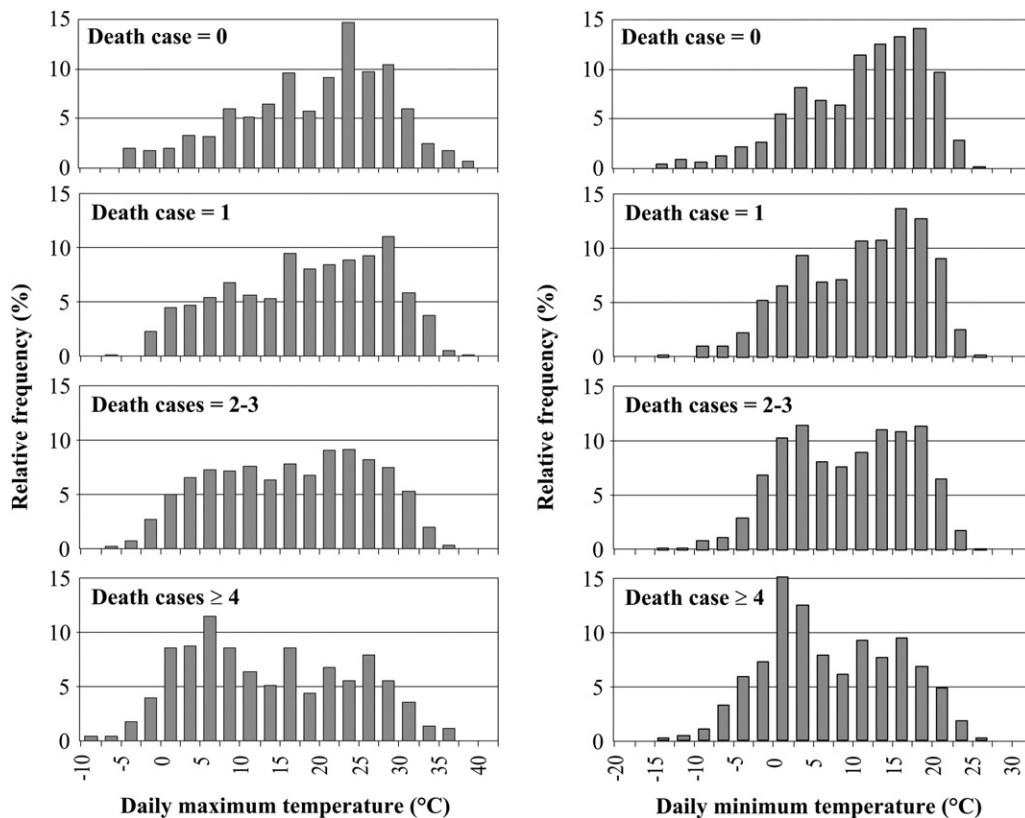


**Fig. 3.** Frequency distribution of minimum and maximum temperature values compared for 0, 1, 2–3, ≥4 cases of acute and chronic cardiovascular deaths.
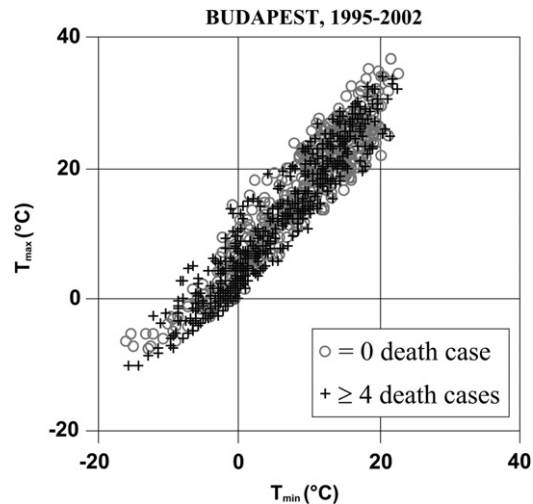
**Fig. 4.** Scatter-plot diagram of the daily maximum and minimum temperature values compared for 0 and ≥4 cases of cardiovascular deaths.

was no statistical difference between the percentages of acute and chronic cardiovascular mortality in different seasons; however, acute cardiac death occurred most frequently in the middle age group (36–60 year) in cold weather.

Detection of health effects due to climate change at this early stage is essential and it needs further investigation. McMichael et al.[1] suggest that the adverse health effects will indicate priorities for planned adaptive strategies. Most of the relevant

**Table 3**
Results of the multiple discriminative analysis.

| Groups of days with different numbers of death cases | Estimated number of death cases for different groups of days | | | | Rate of successful estimation |
|---|---|---|---|---|---|
| 0 Death/day | 0 | 14 | 436 | 0 | 0% |
| 1 Death/day | 0 | 21 | 678 | 0 | 3% |
| 2−3 Deaths/day | 0 | 13 | 1182 | 1 | 98.8% |
| ≥4 Deaths/day | 0 | 7 | 448 | 0 | 0% |
| All | 0 | 55 | 2744 | 1 | 43% |

Estimated values were compared with the real number of death cases. Vectors for discriminative analysis are: $(T_{max})$, $(T_{min})$, $(\Delta_{max}T)$, $(\Delta_{max}p)$, $l$ $(T_{min,\ 850hPa})$, $(T - T_d)$.

studies[5,17,18] were carried out within national mortality statistical database. We used a database of a medico-legal autopsy material, where the cause of death was defined by a detailed post-mortem investigation in every sudden death case, including autopsy results and scene investigation. Histological examination supported the well-defined cause of death by the examination of acute or chronic pathomorphological changes of different cardiovascular deaths.

In our study, a significant negative relationship was detected between daily maximum, minimum temperature and the number of sudden cardiovascular death cases. With these analyses, we confirmed the results of other studies[11,19,20] that mortality was in inverse ration to air temperature. Sudden cardiac death might have been influenced by other meteorological and geographic factors, i. e., relative humidity,[21] air pressure,[22,23] wind,[24] Arctic oscillation,[25] weather fronts,[26,27] geographic location,[4,10,25] and solar wind.[28] The
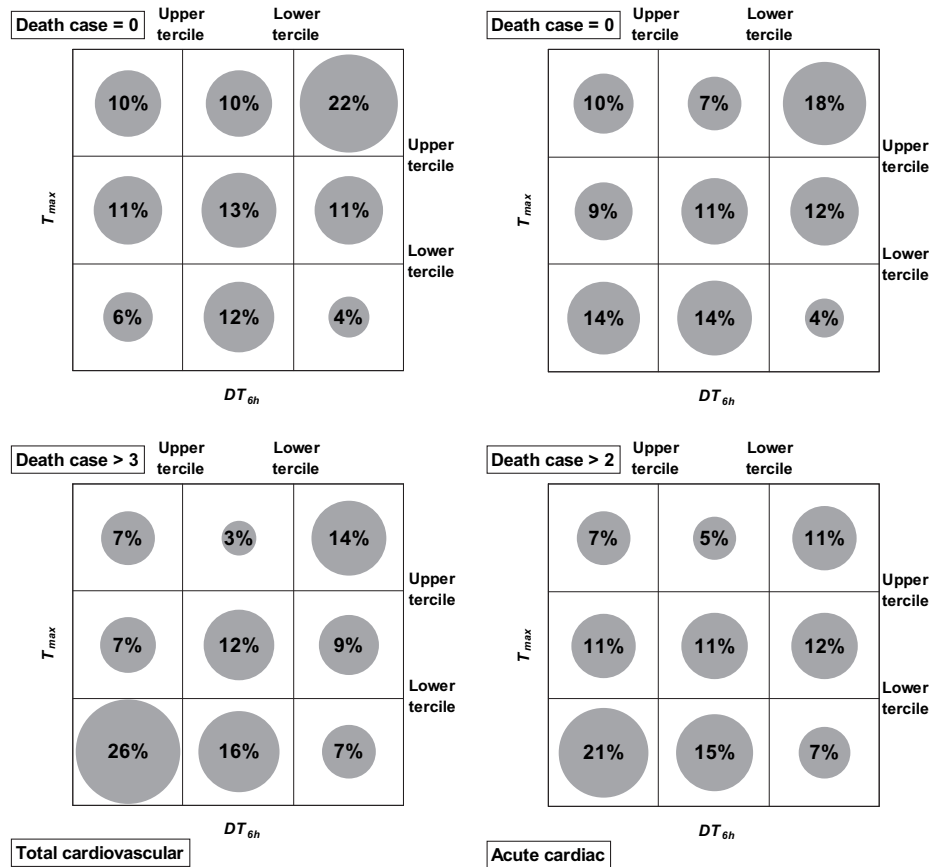


**Fig. 5.** Distribution of daily maximum temperature and the 6-h temperature change when (i) 0 and more than 3 cardiovascular death cases occurred (left panel), (ii) 0 and more than 2 acute cardiac death cases occurred (right panel). Terciles separate the average, the low, and the high temperature values.

## THE TOTAL DAILY NUMBER OF SUDDEN CARDIOVASCULAR DEATH CASES DEPENDING ON THE DAILY AIR PRESSURE BUDAPEST, 1995-2002
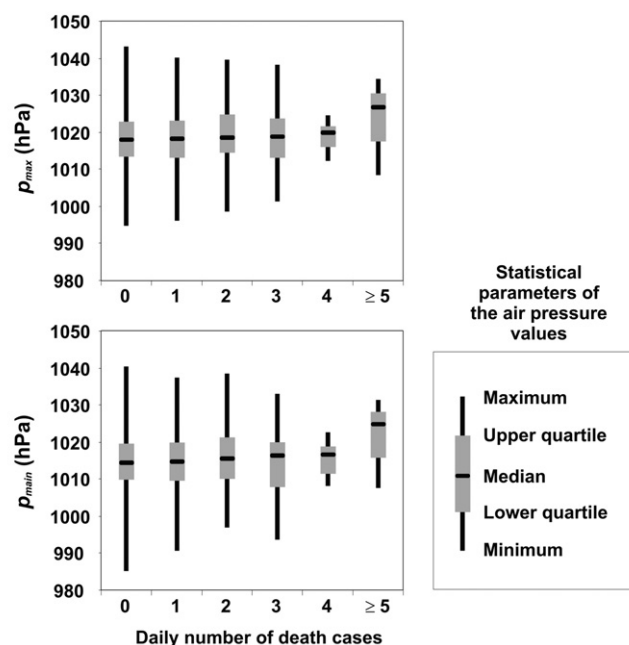


Fig. 6. Distribution of air pressure in case of different daily numbers of acute cardio-vascular death cases.

human response to cold is to implement physiological functions that reduce heat loss, principally by regulating the transfer of heat from the core to the periphery.[4]

Populations typically display an optimum temperature at which the death rate is the lowest,[1] and mortality rises at temperatures outside this comfort zone. In regions with cold and temperate climate the mortality is minimal at about 18 °C, and it rises as temperature falls.[20] Mercer[19] stated that cold may be a more important risk factor for mortality than most people realize, even in countries with mild winter climate. Other contributory natural diseases such as respiratory infections, colds or common flu, chronic obstructive pulmonary disease are also likely to be significant.[29–31]

We found that cardiovascular mortality in older age groups (≥61 years) shows an explicit seasonal distribution, which was not detected in younger age groups, which suggests that seasonal factors are in fact not important in precipitating sudden death events in younger age groups. In cold season, the increased blood pressure and lack of vitamin D are more likely causes forsudden cardiac death, particularly in the elderly.[32,33] Diaz et al.[34] examined the effect of extreme winter temperature on mortality in Madrid for people older than 65, and they used daily maximum temperature ($T_{(max)}$) as the best thermal indicator of the impact of climate on mortality. When total mortality was considered, the maximum impact occurred 7–8 days after a temperature extreme; for circulatory diseases the lag was between 7 and 14 days. When respiratory causes were considered, two mortality peaks were evident at 4–5 and 11 days. Hajat et al.[35] emphasized that elderly people, particularly those in nursing and care homes, were most vulnerable, and the greatest risk of mortality was observed for respiratory and external causes. Interventions to reduce vulnerability to extreme weather should target all elderly people.

Seasonal changes of temperature imply changes in the daily number of cardiovascular diseases.[17,20] An increased winter cardiovascular mortality was detected in Japan.[7,36] Braga et al.[17] found lagged effects of hot temperatures in hot US cities for

myocardial infarction (MI), and in cold cities for pneumonia. Kloner[8] detected approximately one-third more deaths occurring during the months of December and January compared with the period from June to September. There is a relationship between high cardiovascular mortality in the elder ages and the cold season[19]; however, the mechanism by which seemingly mild exposure to cold ambient conditions can increase the risk of death at older age is unclear. In cold the myocardial oxygen supply may be impeded by coronary vasoconstriction especially in vessels damaged by atherosclerosis.[9]

In this study, analysis of the daily 6-h change in air pressure suggests a relationship between increasing air pressure (implying cold weather fronts) and higher rate of acute or chronic vascular death. According to Cagle and Hubbard,[4] air pressure is significantly negatively correlated with death rate, but this effect is extremely small compared to the effect of temperature. We confirmed the previous result[4] that relative humidity and wind did not influence the rate of sudden death, however, another study[37] reported an increased hospital admission at the time of increased wind and low humidity. Takada et al.[21] found a positive relationship between sudden death during competitive sports and dry and cloudy weather conditions.

Shkolnikov et al.[38] estimated the medium and greater levels of intoxication occurred in a quarter of those recorded as dying from cardiovascular disease, and they stated that among young men, whose deaths were ascribed to cardiovascular disease, were in reality simply by alcohol poisoning. The large number of detailed medico-legal autopsies of sudden death cases is essential to determine the exact cause of death and to characterize the pathomorphology of a possible symptom-free disease. In these cases not only BAC tests, but also toxicological investigations of drugs are also useful for the determination of cause of death. We can emphasis the importance of a careful medico-legal post-mortem investigation in every young sudden death with BAC test and full toxicology. The accurate statistical mortality database may provide a huge support for the evaluation of the effects of meteorological conditions on human health and death. We concluded that global warming can be expected to reduce cold related deaths more than it increases the rarer heat related deaths. The environmental change will affect human health in many ways with both beneficial and adverse effects. In order to evaluate the health effects of the global climate change, longer than 10-year long mortally data sets are needed and should be analyzed.

### Conflict of interest

There are no conflicts of interest.

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